Patent Application
Docket No. TI-30652

CERTIFICATE OF MAILING BY EXPRESS MAIL

"EXPRESS MAIL" Mailing Label No. EJ042687293US
Date of Deposit: 8-8-00
I hereby certify that this paper or fee is being deposited with the U.S. Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Box Patent Application, Washington, D.C. 20231.

Type or Print Name: Joy L. Mowery

Signature:

DYNAMIC SLAVE FREQUENCY SELECTION FOR IMPROVING UPLINK FREQUENCY HOPPING WIRELESS COMMUNICATIONS

This application claims the priority under 35 U.S.C. 119(e)(1) of copending U.S. provisional application number 60/185,939, filed on February 29, 2000.

FIELD OF THE INVENTION

The invention relates generally to wireless communications and, more particularly, to wireless communications that utilize frequency hopping techniques.

BACKGROUND OF THE INVENTION

Present telecommunication system technology includes a wide variety of wireless networking systems associated with both voice and data communications. An overview of several of these wireless networking systems is presented by Amitava Dutta-Roy, *Communications Networks for Homes*, IEEE Spectrum, pg. 26, Dec. 1999. Therein, Dutta-Roy discusses several communication protocols in the 2.4 GHz band, including IEEE 802.11 direct-sequence spread spectrum (DSSS) and frequency-hopping (FHSS) protocols. A disadvantage of these protocols is the high overhead associated with their implementation. A less complex wireless protocol known as Shared Wireless Access Protocol (SWAP) also operates in the 2.4 GHz band. This protocol has been developed by the HomeRF Working Group and is supported by North American communications companies. The SWAP protocol uses frequency-hopping spread spectrum technology to produce a data rate of 1 Mb/sec. Another less complex protocol is named Bluetooth after a 10th century Scandinavian king who united several Danish kingdoms. This protocol also operates in the 2.4 GHz band and advantageously offers short-range wireless communication between Bluetooth devices without the need for a central network.

The Bluetooth protocol provides a 1 Mb/sec data rate with low energy consumption for battery powered devices operating in the 2.4 GHz ISM (industrial, scientific, medical)

band. The current Bluetooth protocol provides a 10-meter range and an asymmetric data transfer rate of 721 kb/sec. The protocol supports a maximum of three voice channels for synchronous, CVSD-encoded transmission at 64 kb/sec. The Bluetooth protocol treats all radios as peer units except for a unique 48-bit address. At the start of any connection, the initiating unit is a temporary master. This temporary assignment, however, may change after initial communications are established. Each master may have active connections of up to seven slaves. Such a connection between a master and one or more slaves forms a "piconet." Link management allows communication between piconets, thereby forming "scatternets." Typical Bluetooth master devices include cordless phone base stations, local area network (LAN) access points, laptop computers, or bridges to other networks. Bluetooth slave devices may include cordless handsets, cell phones, headsets, personal digital assistants, digital cameras, or computer peripherals such as printers, scanners, fax machines and other devices.

The Bluetooth protocol uses time-division duplex (TDD) to support bi-directional communication. Spread-spectrum technology or frequency diversity with frequency hopping permits operation in noisy environments and permits multiple piconets to exist in close proximity. The frequency hopping scheme permits up to 1600 hops per second over 79 1-MHZ channels or the entire ISM spectrum. Various error correcting schemes permit data

packet protection by 1/3 and 2/3 rate forward error correction. Further, Bluetooth uses retransmission of packets for guaranteed reliability. These schemes help correct data errors, but at the expense of throughput.

The Bluetooth protocol is specified in detail in Specification of the Bluetooth System, Version 1.0A, July 26, 1999, which is incorporated herein by reference.

In some Bluetooth applications, the master could be an access point (AP) which can afford to transmit at, for example, a 20 dBm power level, while the slave could be a mobile unit with strict power consumption limitations that permit it to transmit only at a substantially lower power level, for example 0 dBm. One conventional example of such a communications system is a cordless telephone system wherein the master is the base unit and the slaves are the mobile phone units. In the exemplary system specified above, there would be an imbalance between the master-to-slave link (i.e., the downlink) and the slave-to-master links (i.e., the uplinks). Considering now a voice application such as the aforementioned cordless telephone system, even when using a receive diversity antenna at the master, such a system would achieve a 10 dB diversity gain with selection diversity. Thus, there would still be a 10 dB power imbalance between the downlink and the uplink transmissions. This situation is illustrated in FIGURE 1.

The example of FIGURE 1 assumes no retransmissions in either direction, because it is typically desired to conserve power consumption both for reception and transmission at the slave. Also, if the master employs some form of transmission diversity, this would further increase the imbalance between uplink and downlink.

It is desirable in view of the foregoing to compensate for power imbalances such as described above, in order to balance the uplink and downlink.

According to the present invention, the uplink slave-to-master transmission frequency can be dynamically selected from a plurality of previous downlink master-to-slave transmission frequencies based on quality measures thereof, which produces improved uplink performance and thereby advantageously reduces imbalances between the uplink and downlink.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 diagrammatically illustrates a power imbalance condition that can occur in conventional wireless communication systems.

FIGURE 2 diagrammatically illustrates an example of a slave frequency selection technique according to the present invention.

FIGURE 3 illustrates exemplary operations which can be performed by the master and slave devices to implement the slave frequency selection technique of FIGURE 2.

FIGURE 4 diagrammatically illustrates pertinent portions of exemplary embodiments of a slave device which can perform the slave operations of FIGURE 3.

FIGURE 5 diagrammatically illustrates pertinent portions of exemplary embodiments of a master device that can perform the master operations of FIGURE 3.

FIGURE 6 diagrammatically illustrates an exemplary technique according to the present invention for dynamically extending the frequency hopping pattern of a master-to-slave link.

FIGURE 7, when taken in combination with FIGURE 5, diagrammatically illustrates pertinent portions of an exemplary embodiment of a master device which supports both selection of slave frequencies and extension of the master frequency hopping pattern according to the present invention.

FIGURE 8, when taken in combination with FIGURE 3, illustrates exemplary operations which can be performed by the master device embodiment of FIGURES 5 and 7.

FIGURE 9, when taken in combination with FIGURE 4, diagrammatically illustrates pertinent portions of an exemplary embodiment of a slave device which supports both selection of slave frequencies and extension of the master frequency hopping pattern according to the invention.

FIGURE 10, when taken in combination with FIGURE 3, illustrates exemplary operations which can be performed by the slave device embodiment of FIGURES 4 and 9.

FIGURE 11 diagrammatically illustrates exemplary simulation results obtained using dynamic slave frequency selection techniques according to the invention.

FIGURE 12 diagrammatically illustrates exemplary simulation results obtained when dynamic slave frequency selection is combined with dynamic extension of the master hopping frequency pattern according to the invention.

DETAILED DESCRIPTION

According to the present invention, a slave monitors the previous N frequency transmissions from the master, and selects one of those N frequencies for the next slave-to-master transmission. Information indicative of the selected frequency is included in the slave's current transmission to the master. The frequency that the slave selects from the N monitored frequencies can be, for example, the monitored frequency that is best according to predetermined selection criteria. The selection criteria can be, for example, one or more conventionally available channel quality measurements.

FIGURE 2 diagrammatically illustrates one example of a slave frequency selection (SFS) scheme according to the invention. The example of FIGURE 2 relates to Bluetooth HV3 (High-quality Voice) communication, and slave frequency selection is implemented by the slave device S_1, with N = 2. Slave device S_1 monitors the previous N frequency transmissions from the master M, namely the transmissions on frequencies f_1 and f_7. Based on desired selection criteria, the slave S_1 selects the best frequency from among the monitored frequencies f_1 and f_7. The selected best frequency is designated as X(J) in FIGURE 2. After having selected frequency X(J), the slave device S_1 transmits to the master on frequency f_8 information indicative of the selected frequency X(J). Thus, the master M knows that the next transmission from slave S_1 will be on frequency X(J). This frequency

X(J) is then used for the next transmission from slave S_1 to the master instead of frequency f_{14} which would otherwise be dictated for slave S_1 by the normal frequency hopping pattern. The transmission from slave S_1 on frequency X(J) will also include information indicative of X(J+1), which is the best of the previous N frequency transmissions from the master, namely f_7 and f_{13}. Thus, after slave S_1 transmits on frequency X(J), the master knows that the next transmission from slave S_1 will be on frequency X(J+1).

If the master M correctly receives the transmission from slave S_1 on frequency f_8, then the master knows that the next transmission from slave S_1 will be on frequency X(J). If the master does not correctly receive the f_8 transmission from slave S_1, then the master indicates in its next transmission to slave S_1, namely in the master transmission on frequency f_{13}, that the next transmission from slave S_1 to the master is to use the most current master-to-S_1 frequency, namely frequency f_{13}. In some embodiments, the master can direct slave S_1 to transmit next on frequency f_7, namely the most recent of the monitored frequencies.

FIGURE 3 illustrates exemplary operations which can be performed by master and slave devices to implement the slave frequency selection scheme illustrated in FIGURE 2. The master transmits the Jth packet on the corresponding frequency in the master's normal frequency hopping pattern, which corresponding frequency is designated as $MS(f_J)$ in FIGURE 3. A bit Y is included in the Jth packet. The bit Y (which can be initially set to a

value of 0) indicates to the slave whether or not slave frequency selection has been overruled by the master. After the Jth master-to-slave packet is received by the slave at 32, the slave selects at 33 the best of the previous N master transmission frequencies $MS(f_J)$, $MS(f_{J-1})$, ... $MS(f_{J-N-1})$ according to any desired selection criteria. The selected frequency is designated as X(J+1) in FIGURE 3. It is thereafter determined at 34 whether the conventional header error correction (HEC) information is correct and whether the value of Y (as received in the Jth master-to-slave packet) is 0. If the HEC information is correct and Y=0, then at 35 the slave device uses the most recent master-to-slave frequency, namely $MS(f_J)$ to transmit the Jth slave-to-master packet. This Jth slave-to-master packet includes information which indicates to the master that the next transmission from the slave will be on frequency X(J+1). On the other hand, if at 34 either the HEC information is incorrect or Y=1, then at 36 the slave device uses frequency X(J) to transmit the Jth slave-to-master packet. This Jth slave-to-master packet includes information indicating that the next slave-to-master transmission will be on frequency X(J+1). As can be seen from the foregoing description, the master sets Y = 0 when the master wants to overrule slave frequency selection, and otherwise sets Y=1.

The frequency X(J+1) can be completely identified in the Jth slave-to-master packet using $\log_2(N)$ bits. For example, if four master transmission frequencies are monitored by the slave (N = 4), then the frequency X(J+1) can be represented by two bits.

If it is determined at 37 that the Jth slave-to-master packet has been received correctly at the master, then, after incrementing the index J, the master notes at 38 that the frequency X(J) will be used to receive the next (the Jth) slave-to-master packet. Also at 38, the master sets Y=1. On the other hand, if at 37 the Jth slave-to-master packet has not been received correctly, then, after the index J is incremented, the master at 39 notes that the next (the Jth) slave-to-master packet will be received on the same frequency (namely $MS(f_J)$) that will be used at 31 to transmit the next (Jth) master-to-slave packet. Also at 39, the master sets Y = 0. After the frequency for receiving the Jth slave-to-master packet has been determined at 38 or 39, the above-described operations at 31-39 are repeated.

FIGURE 4 illustrates pertinent portions of exemplary embodiments of a slave device which can perform the slave operations illustrated in FIGURE 3. The slave device of FIGURE 4 could be provided, for example, in a mobile phone unit in a Bluetooth cordless phone system. Other examples of the slave device include a wireless headset, a palm computer, and the other slave devices specified above. The slave device of FIGURE 4 includes a packet processor 41 coupled between a wireless communications interface 42 and a communications application 43. The packet processor 41 receives communication information from the communications application 43, and can use conventional techniques to assemble the communication information into suitable packets. The packet processor 41

forwards the assembled packets to the wireless communication interface 42 which can use conventional techniques to transmit the packets across a wireless communication link 44 (e.g., a Bluetooth radio link) to a master device. Similarly, packets from the master received at the wireless communication interface 42 via the wireless communication link 44 are conventionally processed by the wireless communication interface and forwarded to the packet processor 41, which in turn disassembles the packets and provides the resulting communication information to the communications application 43. The above-described cooperation among the packet processor 41, the wireless communication interface 42 and the communications application 43 to support bidirectional packet communication with the master over the wireless communication link 44 is conventional and well known to workers in the art.

According to the present invention, an N-stage FIFO register 45 receives from the wireless communication interface and stores therein conventionally available information indicative of the quality of the last N master-to-slave (MS) frequencies on which the master has transmitted to the slave device. A frequency selector 46 has an input connected to the register 45 for receiving therefrom the quality information for the last N master-to-slave transmission frequencies. Based on the quality information received from the FIFO register 45, the frequency selector 46 selects the best of the last N master-to-slave frequencies.

Examples of conventionally available quality information on which the frequency selection can be based include RSSI (received signal strength indicator) or the Bluetooth sync word correlation value. Information indicative of the selected frequency (e.g., X(J+1) from FIGURES 2 and 3) is output from the frequency selector 46, and is stored in a current selected frequency register 47. The previous contents of the current selected frequency register 47 (e.g., X(J) from FIGURES 2 and 3) are at this time shifted into a previous selected frequency register 48. The output X(J+1) is also provided to the packet processor 41 to be included in the next outgoing slave-to-master packet.

A selector 49 has an output which provides to the wireless communication interface 42 information indicative of the frequency at which the next slave-to-master (SM) packet is to be transmitted. The selector 49 has a control input coupled to the output of logic 40 whose inputs are provided by the packet processor 41. More specifically, one input to logic 40 is the HEC information associated with the most recently received master-to-slave packet, and the other input to logic 40 is the bit Y (see FIGURE 3) from the most recently received master-to-slave packet. The logic 40 determines whether the HEC information is correct and Y = 0. If so, then the logic 40 controls the selector 49 appropriately to instruct the wireless communication interface 42 that the frequency of the most recently received master-to-slave

packet ($MS(f_J)$ in FIGURE 3) will also be used for transmission of the next slave-to-master packet.

On the other hand, if the HEC information is incorrect, or if Y is not equal to 0, then the logic 40 controls selector 49 such that information indicative of the frequency X(J) is provided from the register 48 to the wireless communications interface 42 via the selector 49. Thus, X(J) in register 48 indicates to the wireless interface 42 which of the N previous MS frequencies is selected as the next SM frequency.

FIGURE 5 diagrammatically illustrates pertinent portions of exemplary embodiments of a master device which can perform the master operations illustrated in FIGURE 3. The master device of FIGURE 5 could be provided, for example, in the base unit of a Bluetooth cordless phone system. Other examples of the master device include a computer, an access point, a cell phone, and the other master devices mentioned above. The master device of FIGURE 5 includes a packet processor 51 coupled between a wireless communications interface 52 and a communications application 53. The packet processor, wireless communication interface and communications application of FIGURE 5 can cooperate in generally the same fashion as described above with respect to the packet processor 41, the wireless communication interface 42 and the communications application 43 of FIGURE 4, in order to permit the master device of FIGURE 5 to transmit and receive packets to and

from slave devices (such as shown in FIGURE 4) over the wireless communication link 54. According to the invention, the packet processor 51 includes an output 55 which indicates whether or not the current slave-to-master packet has been correctly received. This output 55 is coupled to a control input of a selector 56 which serves as a frequency indicator whose output provides to the wireless communication interface 52 information indicative of the frequency of the next slave-to-master packet. If the output 55 indicates that the most recent slave-to-master packet has not been correctly received, then the selector 56 passes to the wireless communication interface 52 the frequency (at 58) that was used to transmit the last master-to-slave packet. The packet processor 51 includes a further output 57 which provides information indicative of the frequency that has been selected by the slave for transmission of its next slave-to-master packet. This information corresponds to X(J+1) in FIGURES 2-4, and is applied to an input of the selector 56. The selector 56 provides the slave-selected frequency information X(J+1) to the wireless communication interface 52 if the packet processor output 55 indicates that the most recent slave-to-master packet has been correctly received.

The packet processor 51 inserts a value of Y=1 in the next master-to-slave packet if the most recent slave-to-master packet was correctly received at the master. Otherwise, the packet processor 51 inserts a value of Y = 0 in the next master-to-slave packet.

FIGURE 11 diagrammatically illustrates exemplary simulation results using slave frequency selection (SFS) according to the present invention with N = 4 and a single, two antenna receiver at the master. In the example of FIGURE 11, the performance comparison of the master-to-slave transmission (20 dBm) and the slave-to-master transmission (0 dBm) is made for conventional Bluetooth HV3 (High-quality Voice) on an SCO (Synchronous Connection-Oriented) link, with no interference. As shown in FIGURE 11, using SFS can reduce the imbalance between the uplink and the downlink. Although an SCO link is used in FIGURE 11, the SFS technique is also applicable to ACL (Asynchronous Connection-Less) links. SFS is also applicable at high Doppler (i.e., walking speed) conditions.

In the presence of strong interference, the use of SFS according to the present invention can actually produce an imbalance between uplink and downlink wherein the slave-to-master (uplink) performs better. For example, in the presence of microwave interference that is 10 MHZ wide with a 50% duty cycle, the master-to-slave link (downlink) would nominally have a packet error rate floor of 10/140 = 7%, while the slave-to-master link (uplink) using SFS with N = 2 will achieve an error floor of 0.5%. Under these circumstances, it is desirable to improve the downlink master-to-slave performance to balance the links. An exemplary technique according to the invention for improving the downlink master-to-slave performance is illustrated in FIGURE 6.

FIGURE 6 diagrammatically illustrates an example of extending the frequency hopping pattern of a master-to-slave link according to the present invention. This hop extension for the master, also designated herein as HEM, can be advantageous in the presence of a strong interferer, for example a microwave oven. As shown in FIGURE 6, the master transmits a hop extension for master bit (HEMB) which is indicative of the frequency that the master will use in its next transmission. If the master transmits HEMB=0, then the frequency of the master's next transmission will be the normal hopping frequency from its normal hopping frequency pattern. On the other hand, if the master transmits HEMB=1, this indicates that the master will repeat the frequency of the current transmission in its next transmission. In the example of FIGURE 6, when the master is transmitting on frequency f_7, it knows that there will be interference on the next frequency f_{13} in its normal hopping pattern, so the master transmits HEMB=1, thereby indicating to the slave that the current frequency f_7 will be used for the next master-to-slave transmission instead of frequency f_{13} from the normal frequency hopping pattern. In this manner, the master can avoid a strong interferer on frequency f_{13}.

FIGURE 7 diagrammatically illustrates exemplary additions to the master device illustrated in FIGURE 5 to incorporate the HEM operation shown in FIGURE 6. The packet processor 51 (see also FIGURE 5) receives HEMB as in input, and inserts HEMB in the

outgoing master-to-slave packets. Each time that a slave-to-master packet is received, the packet processor 51 outputs a slave-to-master (SM) packet received signal which clocks a latch 94 such that the HEMB transmitted in the most recent master-to-slave packet is latched through to the select input of a selector 99. The output of the selector 99 provides to the wireless interface 52 (see also FIGURE 5) information indicative of the frequency at which the next master-to-slave packet is to be transmitted. Thus, by operation of the latch 94, the HEMB value that was included in the most recently transmitted master-to-slave packet is used to determine the frequency at which the next master-to-slave packet will be transmitted. If HEMB=0 in the most recently transmitted master-to-slave packet, then the selector 99 will indicate to wireless interface 52 that the normal hop frequency from the normal frequency hopping pattern will be used for transmission of the next master-to-slave packet. On the other hand, if HEMB=1 in the most recently transmitted master-to-slave packet, the selector 99 will indicate to the wireless interface 52 that the frequency at which the most recent master-to-slave packet was transmitted is to be repeated for transmission of the next master-to-slave packet.

The value of HEMB that will be transmitted in a given master-to-slave packet (and which will determine the frequency at which the next master-to-slave packet will be transmitted) is produced by a master-to-slave (MS) hop extension determiner 98. The

determiner 98 includes inputs 96 and 97, and responds to these inputs to determine the value of HEMB. The input 96 receives information indicative of master-to-slave link conditions, for example information indicative of any strong interferers which may be operating on master-to-slave frequencies. Interference information, for example the frequency of interferers produced by a microwave oven, is typically readily available. The input 97 of the determiner 98 is coupled to the output of a latch 95 that is clocked by the SM packet received signal produced by the packet processor 51 when a new slave-to-master packet is received. Thus, the latch 95 is clocked together with the aforementioned latch 94. Consequently, at the same time that the latch 94 is clocked to select (via selector 99) the frequency at which the next master-to-slave packet will be transmitted, the latch 95 is clocked to apply to the input 97 of the determiner 98 information indicative of the normal hopping frequency for the master-to-slave packet-after-next.

Based on the normal hopping frequency for the packet-after- next received at 97, and also based on the master-to-slave link condition information received at 96, the determiner 98 determines the value of HEMB that will be transmitted in the next master-to-slave packet. This value of HEMB is indicative of the frequency at which the master-to-slave packet-after-next will be transmitted. For example, if the information received at 96 indicates that the normal hop frequency for the master-to-slave packet-after-next coincides with a strong

interferer, then the determiner 98 outputs HEMB=1, which means that the frequency of the next master-to-slave packet transmission will also be used for the master-to-slave packet transmission-after-next. On the other hand, if the determiner 98 determines that the normal hopping frequency for the packet-after-next does not coincide with a strong interferer, then the determiner 98 outputs HEMB=0, which indicates that the packet-after-next will be transmitted at the normal hopping frequency.

FIGURE 8 illustrates exemplary operations 31A which can be performed by the master device of FIGURES 5 and 7 instead of the operations at 31 in FIGURE 3. It is initially determined at 100 whether or not the normal hopping frequency associated with the (J+1)th packet, namely $MS(f_{J+1})$, is to be avoided, for example due to a conflict with a strong interferer. If the frequency $MS(f_{J+1})$ is to be avoided, then $HEMB_J$, namely the value of HEMB that will be sent with the Jth master-to-slave packet, is set equal to 1 at 102. Otherwise, $HEMB_J$ is set equal to 0 at 103. Thereafter, if $HEMB_{J-1}$, namely the value of HEMB that was sent with the (J-1)th master-to-slave packet, is 0 at 104, then the Jth master-to-slave packet (including Y and $HEMB_J$) is transmitted at 105 on the normal hopping frequency $MS(f_j)$ associated therewith. If $HEMB_{J-1}$ is equal to 1 at 104, then the Jth master-to-slave packet (including Y and $HEMB_J$) is transmitted at 106 on the frequency $MS(f_{J-1})$,

namely the frequency at which the immediately preceding (the (J-1) th) master-to-slave packet was transmitted.

FIGURE 9 diagrammatically illustrates exemplary additions to the slave device illustrated in FIGURE 4 to incorporate the HEM operation illustrated in FIGURE 6. When disassembling a received master-to-slave packet, the packet processor 41 (see also FIGURE 4) can output HEMB to a selector 118 which serves as a frequency indicator whose output provides to the wireless interface 42 information indicative of the frequency at which the next master-to-slave packet will be transmitted. If HEMB=0, then the selector 118 indicates that the normal hop frequency will be used for the next master-to-slave packet transmission. On the other hand, if HEMB=1, then the selector 118 indicates that the frequency that was used for the most recent master-to-slave packet transmission will be repeated for the next master-to-slave packet transmission.

FIGURE 10 illustrates exemplary operations 32A which can be performed by the slave device of FIGURES 4 and 9 instead of the operations at 32 in FIGURE 3. The value of $HEMB_{J-1}$, namely the value of HEMB that was sent in the (J-1)th master-to-slave packet, is inspected at 128. If $HEMB_{J-1}$=0, then the Jth master-to-slave packet is received at 121 on frequency $MS(f_j)$. On the other hand, if $HEMB_{J-1}$=1 at 128, then the Jth master-to-slave packet is received at 129 on frequency $MS(f_{J-1})$.

FIGURE 12 diagrammatically illustrates exemplary simulation results when SFS and HEM according to the invention are combined. In FIGURE 12, the performance comparison of the master-to-slave transmission (20 dBm) and the slave-to-master transmission (0 dBm) is done for HV3 voice on an SCO link with 10 MHZ wide, 50% duty cycle microwave interference. As shown in FIGURE 12, using SFS and HEM can reduce the imbalance between the uplink and downlink.

It will be evident to workers in the art that the embodiments described with respect to FIGURES 2-10 can be readily implemented, for example, by suitable modifications in software, hardware, or a combination of software and hardware, in conventional frequency hopping wireless communication devices such as Bluetooth masters and slaves.

Taking the Bluetooth protocol as an example, the bits corresponding to X(J+1), Y and HEMB can be included in Bluetooth packets by, for example, substituting them for existing bits or adding additional bits after the header.

Although exemplary embodiments of the invention are described above in detail, this does not limit the scope of the invention, which can be practiced in a variety of embodiments.